

Neuromagnetic fields elicited by a bimodal input

C. Nishimura^{1,2}, T. Kumagai², Y. Kikuchi^{2,3}, and H. Endo²

¹*Toho University School of Medicine, Tokyo, Japan*

²*National Institute of Bioscience and Human Technology, Tsukuba, Japan*

³*Tokyo Metropolitan University of Health Science, Tokyo, Japan*

1 Introduction

In recent years noninvasive measurement such as magnetoencephalography (MEG), functional magnetic resonance imaging (f-MRI) and positron emission tomography (PET) has revealed many aspects of the brain function, from sensory projection to cognitive process. And most researchers in this field have studied brain responses to a single modal input. In order to well understand the working brain, however, it is necessary to study neural activities when a multi-modal input is applied. In the present paper we studied responses to a multi-modal stimulus using MEG in combination with MRI imaging.

Responses to a single modal stimulus such as a light flash, a visual pattern and a sound have been reported in many literatures and their origins were estimated in the primary cortex and other areas by using MEG [1,2].

In the paper, in contrast, neuromagnetic responses were measured when a visual and an auditory signals were simultaneously given to a subject, and by analyzing spatio-temporal patterns of MEG, time course of activated regions in the brain and its relation to cognitive processes were investigated. Moreover, MEG responses were discussed in terms of subject's attention.

2 Methods

Subjects were 4 adults (28 – 52 years of age) with normal hearing and vision. In a dark, magnetically shielded room, each subject was seated in a chair with eyes open.

Visual and auditory inputs were simultaneously applied to a subject. The visual input was a flash of a light emission diode (LED) in the left visual field. The LED flashed randomly in either of 2 colors (red and green) for 20ms with random intervals between 1500 – 2000 ms. Frequency of each color was 50%. Synchronized with the light flash, pure tone of either 1kHz or 2kHz was randomly applied to the subject's ears. Frequency of each tone was 50%, which was statistically independent of the light color randomization.

The subject was instructed to pay attention to a specified combination of the light color and the tone pitch (called "target") by mentally counting its occurrences.

Neuromagnetic fields were measured by the 64-channel whole-cortex type MEG system (CTF Inc., Canada) with the onset of the bimodal stimulation being a trigger. They were detected for 1000 ms consisting of a 100 ms-pretrigger period and a 900 ms-posttrigger period at 625 Hz-sampling rate. Their offsets were adjusted referring the 100 ms-pretrigger period and then they were band-pass filtered (0.01 – 30 Hz) for noise reduction. For each combination of light and tone, 40 responses were averaged to obtain the event related field (ERF). Then, multidipole estimations were carried out based on the Grynszpan-Geselowitz's equation. The location as well as the magnitude of the equivalent current dipoles (ECDs) was estimated during the period between 84.8 – 348.8 ms after the onset of the stimulus with 1.6 ms-step. The locations of the estimated dipoles were overlaid on the subject's MRI which was T1 weighted to emphasize anatomy.

3 Results

Subjects correctly detected the targets in almost all experimental sessions. Figure 1 shows changes in mean ECD magnitudes in the period between 84.8 – 288.0 ms for all subjects. Spatiotemporal distributions of the estimated ECDs during the period 84.8 – 348.8 ms after onset of the target stimulus are shown in Figure 2 for 2 subjects where the target was "green" and "1kHz".

There is a common pattern in those distributions. In the period about 90 – 130 ms, 3 ECDs were estimated in the right visual cortex and in both auditory cortices, respectively, throughout the period. Their magnitudes were 20 – 40 nAm. In the period about 130 – 150 ms, ECDs were estimated in basal ganglia (BsGa) and hippocampus (HP) as well as parietal lobe. The mean ECD magnitude was more than 50 nAm. In the period about 160 – 220 ms, ECDs were estimated mainly in parietal and temporal areas including angular gyrus (AG),

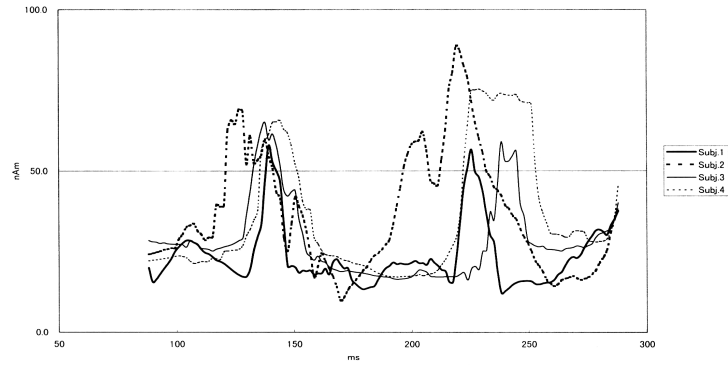
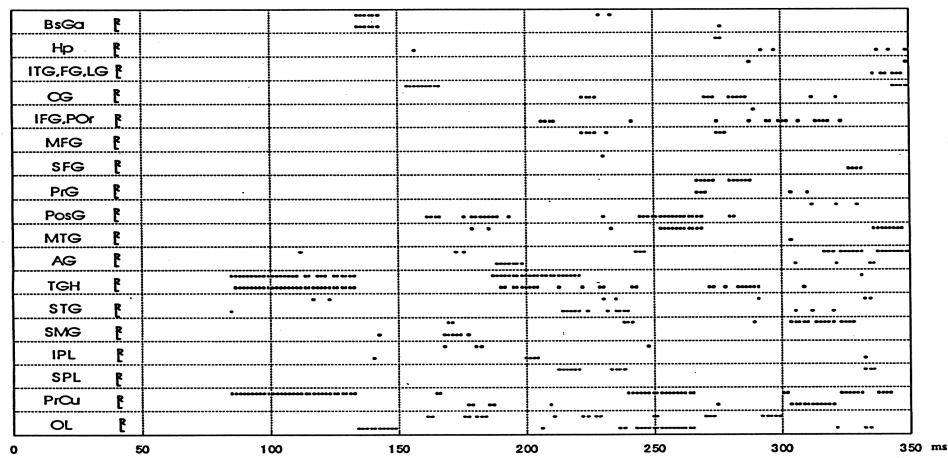


Figure 1: Mean ECD magnitude (84.8 – 288.0 ms).

Subject 1



Subject 2

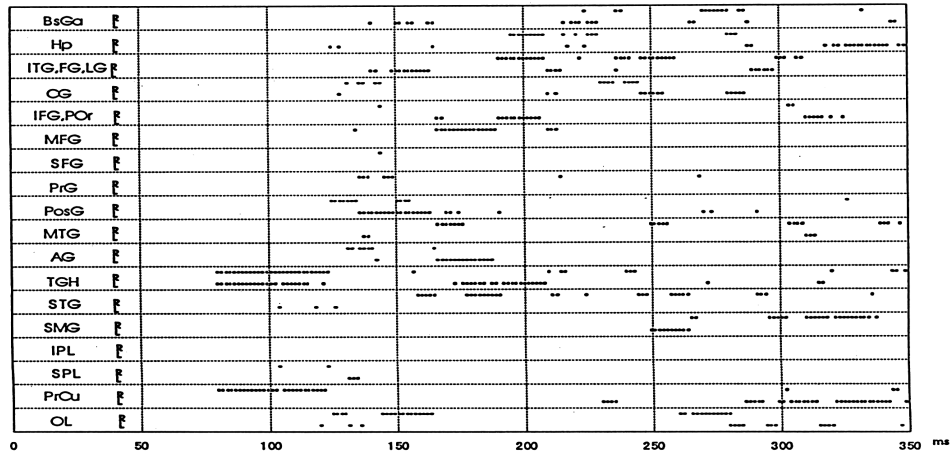


Figure 2: Distribution of estimated ECD.s

BsGa: basal ganglia, HP: hippocampus, ITG: inferior temporal gyrus, FG: fusiform gyrus, LG: lingual gyrus, CG: cingulate gyrus, IFG: inferior frontal gyrus, PO: pars orbitalis, MFG: middle frontal gyrus, SFG: superior frontal gyrus, PrG: precentral gyrus, PosG: postcentral gyrus, MTG: middle temporal gyrus, AG: angular gyrus, TGH: transverse temporal gyri of Heschl, STG: superior temporal gyrus, SMG: supramarginal gyrus, IPL: inferior parietal lobule, SPL: superior parietal lobule, PrCu: precuneus, OL: occipital lobe, R: right hemisphere, L: left hemisphere.

supramarginal gyrus (SMG), inferior parietal lobule (IPL), postcentral gyrus (PosG), superior temporal gyrus (STG) and superior temporal sulcus, as well as visual and auditory cortices. Their magnitudes were 10 – 40 nAm with the exception of Subject 2's hippocampal activity (80 - 100 nAm) around 200 ms. In the period about 220 – 240 (250 for Subjects 3 and 4) ms, ECDs were estimated again in basal ganglia. The mean magnitude was more than 40 nAm. In the period about 240 – 300 ms, ECDs were estimated mainly in middle temporal gyrus (MTG), AG, PosG, cingulate gyrus (CG) and inferior temporal gyrus (ITG) as well as visual and auditory cortices. In addition, after about 320 ms, ECDs were frequently estimated in HP, BsGa and CG.

In addition to the above-mentioned common features, ECDs in the frontal area were observed for all subjects, although they did not necessarily coincide in the time course among subjects. There were two major areas in the frontal lobe where ECDs distributed: (1) around the orbitofrontal area including a part of inferior frontal gyrus (IFG) and pars orbitalis (POr), and (2) around the dorsolateral prefrontal area including a part of superior frontal gyrus (SFG), middle frontal gyrus (MFG) and precentral gyrus (PrG). In about 200 – 310 ms, ECDs around the orbitofrontal area were observed for 3 subjects, while in about 160 – 210 ms and about 300 – 320 ms for one subject. As to the ECDs around the dorsolateral prefrontal area, 2 subjects showed them in about 140 – 210 ms and 2 subjects in about 220 – 330 ms.

Figure 3 shows ERFs detected by some sensors over the right hemisphere for all combinations of light and tone where the combination of green light and 1 kHz-tone was specified as the target. Comparing ERF for the target with that for the non-target which means the combination of red light and 2 kHz-tone where neither color nor pitch coincides with that of the target, the difference in the late component (after about 350 ms) was remarkable. In semi-target cases, where either color or pitch, but not both, coincides with that of the target, moderate differences from the non-target were observed in the late component.

4 Discussion

The results reveal some aspects of integration process of bimodal inputs in the brain. First, they show the time by which the integration is carried out and discrimination is made. As a matter of form, the experimental procedure in this study agrees with a paradigm known as the “odd-ball paradigm” in which some aspects of human response to environment such as novelty detection and attention

paying can be physiologically observed [3], since target appearance was randomized with the frequency of 25% and the subject was required to pay attention to it by mental counting. The results show that the late component of ERF was prominent for the targets compared with non-targets and semi-targets in all possible combination of the visual and auditory stimuli, showing that the task can be practically be regarded as the odd-ball task and the late component of ERF corresponds to P300m which is usually observed in a single modal odd-ball task [4]. One of the origins of P300m is reported to be in HP [5]. The result that after about 300 ms ECDs were estimated in HP is consistent with the report. Therefore, it can be concluded that by this time (around 350 ms) the inputs through audition and vision would have been associated in the brain and discrimination whether it was the target or not would have been made.

As to the early component (about 90 - 130 ms), the spatial pattern of ERF was well fitted by 3 ECDs. Their locations were estimated in the left and right auditory areas and the right visual area consistent with binaural hearing and hemifield (left) vision, showing that at this stage each input signal is processed in modality-specific cortical area.

In about 130 – 150 ms, mean magnitude of ECDs was more than 50 nAm for all subjects. This is mainly due to ECDs estimated in BsGa and HP. Similar activities were observed in 220 – 240 ms.

In about 160 – 210 ms, activities in association cortices including parietal and temporal lobes prevailed. Then, in 220 – 240 ms, activity in BsGa was again observed, thereafter activities were observed in a wide variety of cortical area including frontal and inferior temporal areas as well as parietal and other temporal areas. From the fact that in our experiment activities in BsGa were observed in some restricted periods for all subjects and distribution pattern of ECDs changed after each period, it can be said that activities in BsGa would have some influences over the way of information processing in the brain [6].

In addition, ECDs in the frontal area, especially around the orbitofrontal area and the dorsolateral prefrontal area are thought to be related to attentional process including deviance detection and working memory which is crucial in carrying out the experimental task.

The activities in visual and auditory areas were intermittently observed through the whole period for all subjects, suggesting that during the period the sensory information would be frequently required and referred to.

References

1. R.L. Rogers, S.B. Baumann, A.C. Papanicolau, T.W. Burbon, S. Alagarsamy, and H.M. Eisenberg, "Localization of the P3 sources using magnetoencephalography and magnetic resonance imaging", *Electroencephalogr. Clin. Neurophysiol.* **79**, 308-321, 1991.
2. R.L. Rogers, A.C. Papanicolau, S.B. Baumann, and H.M. Eisenberg, "Neuromagnetic evoked visual fields following infrequent stimulus", in *Biomagnetism: Clinical aspects*, H. Hoke, *et al.*, Eds. Amsterdam: Elsevier, 1992, pp.203-206.
3. C.C. Duncan-Johnson and E. Donchin, "On quantifying surprise: The variation of event-related potentials with subjective probability", *Psychophysiol.* **14**, 456-457, 1977.
4. Y. Kikuchi, H. Endo, S. Yoshizawa, M. Kita, C. Nishimura, M. Tanaka, T. Kumagai and T. Takeda, "Human cortico-hippocampal activity related to auditory discrimination revealed by neuromagnetic field", *NeuroReport* **8**, 1657-1661, 1997.
5. C. Nishimura, T. Kumagai, Y. Kikuchi and H. Endo, "Neuromagnetic fields elicited by multimodal inputs", in *Recent Advances in Biomagnetism*, T. Yoshimoto, *et al.*, Eds. Sendai: Tohoku University Press, 1999, pp.700-703.
6. C.D. Marsden, "The mysterious motor function of the basal ganglia: The Robert Wartenberg Lecture", *Neurology*, **32**, 514-539, 1982.

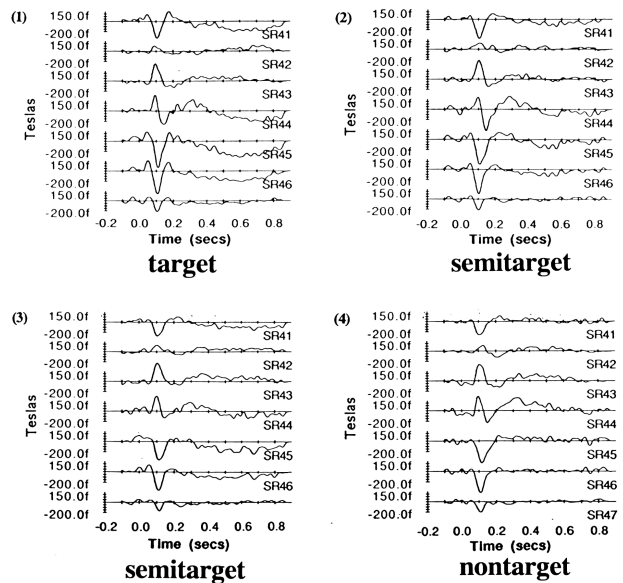


Figure 3: Elicited magnetic fields over the right hemisphere for all combinations of light color and tone pitch (Subject 1).

- (1) Target: Green and 1 kHz.
- (2) Semi-target: Red and 1 kHz.
- (3) Semi-target: Green and 2 kHz.
- (4) Non-target: Red and 2 kHz.